Contaminant Plume Modeling at the Main Installation of the Former Memphis Depot

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Project Background

CH2M HILL is working with engineering-environmental Management (e²M) to investigate potential water quality impacts to the Memphis Sand Aquifer beneath the former Main Installation portion of the former Defense Distribution Center (Memphis, Tennessee) (hereafter referred to as the Memphis Depot). Specifically, this work involves reviewing geologic and hydrogeologic properties of the fluvial aquifer, performing modeling of those properties, and defining the effect that contamination may have on the underlying Memphis Sand Aquifer as the contamination passes through the fluvial aquifer and into deeper geologic units.

Results from this work may be used to support evaluation of further remedial action requirements for groundwater beneath the Main Installation. The former Memphis Depot is located in the southwestern portion of Memphis, Tennessee.

Project Scope

The objective of this effort is to investigate potential water quality impacts to the Memphis Sand Aquifer that may occur due to vertical transport of VOC contamination from the overlying fluvial aquifer at the Memphis Depot, Main Installation site. The stratigraphy at the site is characterized by three primary aquifer units; the fluvial aquifer, the Jackson Claiborne group; and the Memphis Sand aquifer. The fluvial aquifer is the uppermost formation that represents the water table aquifer across the site. The Jackson Claiborne group is a laterally heterogeneous unit that underlies the fluvial aquifer. Where coarse grained sediments are present, this formation is locally referred to as the intermediate aquifer. In other areas, where the Jackson Claiborne group is comprised of more fine grained sediments, the unit acts as an aquitard between the fluvial aquifer and the underlying Memphis Sand Aquifer. The Memphis Sand aquifer is the deepest of the three units and represents a major regional aquifer supplying water to numerous communities across the Mississippi Embayment. In most areas, even where the Jackson Claiborne group is coarse grained in nature, significant thicknesses of low permeability material are present, preventing direct connection between the fluvial and Memphis Sand aquifers.

Several groundwater contaminant plumes have been identified within the fluvial aquifer on the Main Installation of the Memphis Depot. These plumes are in close proximity to a hole, or window, through the low permeability confining units that in most areas separate the fluvial, intermediate, and Memphis Sand Aquifers. Due to the presence of this window within the confining units, the potential exists for shallow groundwater contamination to migrate vertically downward into the Memphis Sand Aquifer and degrade water quality. The approach that was used in this analysis was to simulate the movement of VOC contamination through the fluvial aquifer to the window, and then evaluate the implications of the predicted mass flux of contaminants through the window once they reach the underlying Memphis Sand Aquifer using a three-dimensional solute transport model.

The scope of this work is to forecast the future behavior of the VOC plumes within the fluvial aquifer, and then once they reach the window and flow into the Memphis aquifer, what the potential is for significant downgradient transport within the Memphis Sand Aquifer. In particular, this evaluation focused on the probability that VOC contamination could eventually reach the Allen Well Field, located about 1.3 miles down-gradient of the window within the Memphis Sand Aquifer. The Allen well field is operated and maintained by Memphis Light, Gas and Water (MLGW) to provide drinking water for the City of Memphis.

This memorandum describes the analysis performed to evaluate the potential for future migration of VOC contamination observed on the Main Installation of the Memphis Depot to downgradient receptors; primarily the Allen Well Field. The memorandum is divided into four sections; 1) Site Data Review and Evaluation, 2) Alternatives Development, 3) Contaminant Transport Model Simulations, and 4) Results and Conclusions.

Site Data Review and Evaluation

Existing data for the Main Installation site were collected and reviewed to aid in the development of a site conceptual model. The types of reports and data reviewed include:

- Long Term Monitoring Reports from 2007 and 2008, provided by e²M.
- Main Installation Enhanced Bioremediation Treatment Year One Remedial Action Operations Report from July 2008, provided by e²M.
- Phase 2 Well Installation Technical Memorandum including lithologic cross-sections (2007), provided by e²M.
- MIP Status Reports; Main Installation Source Area Investigation (2008), provided by e²M.
- Aquifer testing data (collected by CH2M HILL since the beginning of the work at the Depot).
- Monitored Natural Attenuation Study from 2001, provided by CH2M HILL.
- General information on the Memphis Sand Aquifer including well location maps. These data were obtained from the literature as well as U.S. Army Corp of Engineers files.

Out of all the information reviewed, the Long Term Monitoring Report published by e²M in April 2008 was considered the latest and most accurate data for characterization of current site conditions. Information obtained from this report includes current well locations at the site, groundwater levels, current TCE and PCE concentration distributions, as well as historic water level and contaminant concentration data.

Conceptual Site Model

The Main Installation area evaluated in this study is part of the Memphis Depot located in Shelby County, Memphis, Tennessee. The Main Installation (MI) comprises an approximate area of 578 acres (see Figure 1). Several PCE and TCE plumes are present at the site in the shallow fluvial unconfined aquifer. The groundwater levels in the fluvial aquifer suggest a general groundwater flow direction from north-east to south-west and from south-west to north-east converging on a relatively stagnant low point which lies approximately in the center of the site, close to well location MW-108 (refer to Figure 2). Most of the flow that accumulates in this area appears to flow toward the south. However, some portion of the flow in the northern part of the area also appears to flow north (towards well MW-90). In this area, the Jackson Claiborne unit is comprised of relatively coarse grained material, and the intermediate aquifer provides a conduit for groundwater flow. Further, the low permeability aquitard between the intermediate aquifer and the underlying Memphis Sand aquifer is absent. These features, which are relatively common in the Memphis Area, are referred to as "windows" in the fluvial/intermediate aquitard, and are characterized by relatively strong downward gradients. As such, these structures represent potential conduits where contamination present in the fluvial and intermediate aquifers can migrate vertically downward and enter the underlying Memphis Sand Aquifer. At the window on the Main Installation, a clay layer which extends above the water table surrounds the window to the north, west and east, preventing direct fluvial aquifer discharge to enter the window from these directions. Figure 3 shows the location of the clay layer, surrounding the window. While some of the groundwater entering the window flows around the clay and enters the window from the south-east within the fluvial aquifer, additional groundwater flow appears to migrate downward into the intermediate aquifer, and then travels north beneath the overlying clay aquitard and enters the window from the south-west. The cross-section presented in Figure 4 illustrates the configuration of the different aquifer and aquitard layers, and supports the conceptual model of shallow fluvial aquifer groundwater moving below the aquitard separating the fluvial and intermediate aquifers and into the intermediate aquifer. Once the contamination reaches the intermediate aquifer, it provides a permeable conduit for groundwater to reach the window and migrate vertically downward into the Memphis Sand aquifer. To provide a more quantitative characterization of the flow patterns and flow rates through the intermediate aquifer near the window, a groundwater contour map was developed using water level data from wells MW-63, MW-108, MW-207A, MW-90, MW-211, MW-39A, MW-210A, MW-202A, MW-38, MW-140, and MW-34. The results of this analysis suggest a north to northwesterly flow direction and a local horizontal hydraulic gradient of 0.021 ft/ft in the intermediate aquifer sands. Figure 5 shows the intermediate aquifer contour levels.

PCE Plumes

Three significant PCE plumes are present at the Main Installation site (refer to Figure 6 for a view of the PCE plume isopleths). One is located in the south-west quadrant of the site, termed the West-Central plume (see Figure 7), and its source area is centered near well

MW-39A, which is screened in the intermediate aquifer. The second significant plume is located in the south-west corner of the site and is termed TTA-1 (North and South). The two sources of this plume appear to be located south and east of building 972; the plume then follows the groundwater flow path towards the West-Central plume and it appears to merge with it. The third significant PCE plume is located in the south-east corner of the site and is termed TTA-2. This plume is centered around Building 265. Due to the groundwater flow path in this area of the site, it appears that this plume flows south and never reaches the window.

The TTA-1 and TTA-2 source areas are currently being actively treated by enhanced biotreatment using injection of sodium lactate into injection wells within the source area.

For the purposes of transport modeling, it was assumed that the West-Central Plume was the primary source of PCE contamination moving toward the fluvial aquitard window. As a result, only the West-Central plume was taken into consideration in this analysis. The exact flow path of PCE to the window is unclear. The groundwater elevations observed in the fluvial aquifer suggest a predominantly southern flow direction from the central portion of the site, not north toward the window. Further, the fluvial aquifer groundwater contours depicted on Figure 2 suggest that the water entering the window originates from the eastern portion of the site, north of any substantial sources of contamination. However, elevated TCE and PCE concentrations have been measured in the wells within and in the vicinity of the window, suggesting a pathway does exist for contaminants observed within the major plumes at the site to reach the window. As discussed previously, the most likely pathway for this to occur is through the more permeable zones within the intermediate aquifer. For the purposes of the transport modeling analysis, it was assumed that the PCE flow path was primarily within the intermediate aquifer between the suspected source area and the aquitard window along a north-west pathway under the clay layer, as shown in Figure 8.

TCE Plumes

One significant TCE plume occurs at the MI site. It is located in the vicinity of well MW-62, just south-west of the clay layer surrounding the window, and is referred to as the Building 835 plume (See Figures 7 and 9). It is assumed that the plume flows south-east along the edge of the low permeability clay layer, then reaches the PCE plume path before shifting flow direction to the north, flows under the clay unit, and into the window. Figure 10 shows the assumed TCE plume path in the intermediate aquifer between the suspected source area and the window. This flow path was assumed to be the path taken by the TCE contamination for the purposes of the transport modeling analysis described below.

Model Simulations

The West-Central PCE plume and the Building 835 TCE plume were modeled over fifty years to determine their behavior and potential threat to drinking water wells in the Allen well field. The approach taken to evaluate plume movement at the site was to simulate the contaminant transport process in a two step procedure. First, each plume was modeled from its source to the aquitard window within the fluvial and intermediate aquifers using a simple two-dimensional analytical solute transport model: BIOSCREEN. In the second step, the transient VOC concentrations at the window computed by BIOSCREEN were combined with independently estimated groundwater flux quantities to the window, to yield transient contaminant mass and groundwater flux values that could be used as input to a three-dimensional groundwater flow and solute transport model of the Memphis Sand Aquifer. The groundwater flow and solute transport models used in this step of the analysis were MODFLOW and MT3D, respectively. The application of these tools to simulate solute transport at the MI is discussed below.

Main Installation Fluvial Aquifer Modeling – BIOSCREEN

BIOSCREEN is a Natural Attenuation Decision Support System, made available by the EPA. The version of BIOSCREEN that was used in this study is Version 1.4. The model is a Microsoft Excel based spreadsheet tool that calculates contaminant concentrations downstream of a plume source over time using an analytical form of the advection-dispersion solute transport equation.

Model Assumptions

BIOSCREEN requires the input of various site parameters that describe the subsurface conditions within the plume area. Available data that was used as input to the model includes aquifer hydraulic conductivity, horizontal hydraulic gradient, and aquifer dispersivity that was estimated from plume length. Also, due to the limitations of the one-dimensional approach used in BIOSCREEN, it was necessary to simulate plume movement along a straight line, even though in reality the plumes do not follow a straight path towards the window. The plume length and total estimated migration path lengths were input to BIOSCREEN as the true distance the plume would migrate, even though they do not move along a straight line as is simulated. This simplifying assumption in BIOSCREEN will not significantly alter the predicted VOC concentrations at the window. The plume travel distance for PCE was estimated at 1800 ft and the TCE plume travel distance was estimated at 1500 ft. Based on the empirical relationship between plume length and dispersivity developed by Xu and Eckstein (1995) included in the BIOSCREEN package, a longitudinal dispersivity of approximately 30 feet was estimated. The effective porosity used in these simulations was assumed to be 0.15. The average hydraulic gradient, considering groundwater elevations in both the fluvial and intermediate aquifers is approximately 0.012 ft/ft. The attenuation rates for each contaminant were estimated by calibrating the BIOSCREEN concentration predictions along the current plume expression to the observed concentrations at various wells along the plume path. The wells used for the calibration show a decline in concentration with distance from the source, allowing for the computation of an effective attenuation rate. The calibration was performed by varying the attenuation rate and keeping all other inputs unchanged, until good agreement was obtained between the observed and simulated contaminant concentrations. The time period at which the simulated and observed concentrations were compared was the estimated travel time between the source area and the window, including the effects of adsorption. The calibrated graphs for the modeled concentrations versus actual concentrations of contaminant are presented in Figures 11 and 12. It was necessary to compare currently observed VOC concentrations with future simulated concentrations because the BIOSCREEN model assumes no contamination is present downgradient of the source areas as an initial condition, and it was necessary to allow the model to replicate the VOC migration to the window before the comparison was made. It should be noted that the degradation rates computed using this method may include other attenuation factors that act to reduce contaminant concentrations during transport other than just biological processes. The input parameters used in the BIOSCREEN simulations are summarized in Table 1 below.

TABLE 1
BIOSCREEN Input Data – Intermediate Aquifer Site Characterization

Input	PCE	TCE
Seepage Velocity	1159 ft/yr	1159 ft/yr
Hydraulic Conductivity	40 ft/d	40 ft/d
Hydraulic Gradient	0.012 ft/ft	0.012 ft/ft
Effective Porosity	0.15	0.15
Retardation Factor	2.2	1.7
Plume Length	1800 ft	1500 ft
Longitudinal Dispersivity	30 ft	30 ft
Transverse Dispersivity	3.0 ft	3.0 ft
* 1st Order Attenuation Rate	0.5 per yr	0.8 per yr

Notes: * From BIOSCREEN well data calibration

The other assumption that must be made in BIOSCREEN is to provide an estimate of the VOC mass present in the source area. Insufficient data exists for the source areas at the site to allow for an accurate calculation of source mass to be made. As an alternative, several simulations were performed that bounded the potential source conditions that may occur in the future. One set of simulations were run assuming that the source has a relatively limited mass, and that the concentrations in the source area will decline over the 50 year simulation. The other set of simulations assumed a source area with sufficient mass such that the source area concentrations stay relatively constant over the 50 year simulations. More specifically, four different scenarios were simulated for each VOC to model the transport of the PCE and TCE plumes to the window:

Scenario 1: Finite source with degradation

Scenario 2: Finite source without degradation

Scenario 3: Infinite source with degradation

Scenario 4: Infinite source without degradation (worst case)

BIOSCREEN requires an assumption to be made of the initial mass of contamination in the source area. This mass then declines over the duration of the simulation. The actual mass of contamination present in the source areas of the site are not well defined, however recent MIP studies suggest it is fairly small. To bound the range of possible site conditions, the scenarios performed herein assume a range of source conditions. The simulations assuming a finite source assume an initial contaminant mass that results in a declining source term over the fifty-year simulation period. The simulations assuming an infinite source term (constant source concentration over the simulation) were modeled assuming a large enough mass such that the resulting source term did not decline over the course of the simulations. Therefore, the initial contaminant mass entered into the model was not based on field measurements, but was rather selected to produce the desired range in source conditions.

The finite source was modeled in BIOSCREEN with an initial contaminant mass of 2,000 kg, which results in a declining source area concentration over time. For example in scenario 1, for the PCE plume, the maximum concentration at the beginning of the simulations in the source area is 234 μg/L. After 5 years, the PCE concentration in the source area is 214 μg/L, declines to 164 μg/L after 20 years, 138 μg/L after 30 years, and finally declines to 97 μg/L by the end of the 50 year simulation. The infinite source was modeled with an initial mass of 10,000 kg, which results in a constant source area concentration over time of approximately 200 ug/L.

Model Results

During all of the simulations performed, the BIOSCREEN model was configured to provide concentration estimates at five year time increments every 200 feet along the path of the plume. Of primary interest for this analysis was the predicted concentration over time at the aquitard window. These concentrations will be used as input to the MODFLOW/MT3D simulations to evaluate contaminant transport through the Memphis Sand Aquifer. The simulated VOC concentrations at the aquitard window for each of the four scenarios are given in Tables 2A (for PCE) and 2B (for TCE). The simulated concentration time series at the aquitard window for each contaminant are also shown on Figures 13 and 14.

TABLE 2A
BIOSCREEN Outputs for PCE– Plume Concentration at the Window

Time (years)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
5	34	206	34	210
10	32	200	35	219
15	29	184	34	215
20	27	168	33	211
25	24	154	33	208
30	22	141	32	204
35	20	129	32	200
40	19	118	31	197
45	17	108	31	193
50	16	99	30	190

Notes: Concentrations are given in μg/L

TABLE 2B
BIOSCREEN Outputs for TCE– Plume Concentration at the Window

Time (years)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
5	13	127	13	128
10	13	122	13	127
15	12	118	13	126
20	12	114	13	126
25	11	110	13	125
30	11	107	13	124
35	11	103	13	123
40	10	99	13	122
45	10	96	12	121
50	10	93	12	120

Notes: Concentrations are given in μg/L

Memphis Aquifer Model – MODFLOW/MT3D

The groundwater flow in the Memphis aquifer was simulated with the three-dimensional finite difference model MODFLOW Version 2000 (McDonald and Harbaugh, 1988) released and distributed by the United States Geological Survey (USGS). The transport of contaminants was simulated using MT3DMS which was developed by Chunmiao Zheng (Zheng 1990) and is now released by the US Environmental Protection Agency (USEPA). MT3DMS works in conjunction with MODFLOW which provides hydraulic head data that is used by MT3DMS to compute contaminant transport. The model interface and pre- and post-processor Groundwater Vistas (Groundwater Simulations, Inc.) was used to allow for efficient data management and analysis of simulation results.

Conceptual Model

The majority of the hydraulic data used in the MODFLOW model of the Memphis Sand aquifer were obtained from a previous model of the site developed to support the Off-Depot Groundwater Remedial Design (CH2M HILL, 2006). The horizontal hydraulic gradient in the Memphis Sand aquifer in the Depot area is approximately 6.4×10^{-4} ft/ft, and that value was used in this analysis as well. The groundwater flow is generally North-East to South-West in the area of interest, which comprises the Main Installation and the Allen well field. Therefore, local groundwater flow patterns could potentially transport contaminants entering the Memphis Sand aquifer from the aquitard window directly toward the Allen Well Field production wells.

Model Assumptions and Setup

The finite difference model grid was designed to provide high resolution beneath the aquitard window area and along the primary flow path between the window and the down-gradient Allen Well Field wells (see Figure 15). Greater resolution is required near the window to minimize numerical dispersion in the transport calculations simulating the response of the aquifer system to mass moving from the overlying fluvial aquifer into the regional Memphis Aquifer. The overall grid dimensions of this model are approximately 10,400 ft long, 5,600 ft wide, and 200 ft deep. The discretization in the high resolution area is 10 feet by 10 feet with the grid spacing then increasing away from the source area reaching a maximum cell width of 51 ft and cell length of 141 ft in outlying areas of the model grid. The model grid includes a total of 317 rows, 188 columns and 5 layers.

The horizontal hydraulic gradient was simulated in the model by assuming a steady flow with a constant head boundary condition imposed at the upstream end and at the downstream end of the model in each layer. The Memphis aquifer is assumed to be totally confined for modeling purposes. All other aquifer data properties assumed for this modeling effort are provided in Table 3.

TABLE 3
Memphis Aquifer Model Input Data

Property	Value
Hydraulic Gradient	0.00064 ft/ft
Longitudinal Hydraulic Conductivity	50 ft/d
Transverse Hydraulic Conductivity	50 ft/d
Vertical Hydraulic Conductivity	5 ft/d
Total Porosity	0.39
Effective Porosity	0.2
Longitudinal Dispersivity	40 ft
Transverse Dispersivity	4 ft
Vertical Dispersivity	0.4 ft
Storage	0.01 per ft

Notes: The aquifer was considered homogeneous in soil composition throughout the study area.

In addition to basic aquifer properties, adsorption and degradation of contaminants were also incorporated into the model simulations. Adsorption was assumed to follow a linear isotherm while degradation was assumed to follow first order decay model. Attenuation rates assumed for PCE and TCE were the same as those used in the fluvial aquifer BIOSCREEN model.

The transport of contaminants into the Memphis aquifer from the overlying fluvial aquifer through the window was modeled as an injection well into the first layer of the model grid. The plume was created by assuming a constant injection rate of 12,000 ft^3/d (based on the observed hydraulic gradient and the assumed hydraulic conductivity of the intermediate aquifer in the vicinity of the window). The concentration of the injection stream was specified based on the forecasted contaminant concentrations at the aquitard window over time from the BIOSCREEN model (See Figures 13 and 14). Based on the modeled ranges of concentrations that enter the window, it is estimated that 0.012 lb/day to 0.16 lb/day of PCE mass enter the window over time for the different scenarios. Similarly, for TCE the estimated mass flux entering the window ranges between 0.0076 lb/day and 0.09 lb/day. The Allen wells closest to the Main Installation and still in operation are well 114 (located at 1198 Mallory Ave.) and well 118 (located at 1280 Whitmore Ave.). It was assumed that these wells are operating continuously and generating resulting cones of depression within the Memphis Aquifer. Specific pumping schedules for either of the wells were unavailable. To simulate the effects of groundwater withdrawal from the production wells on groundwater levels in the Memphis Aquifer, constant head boundary conditions were imposed at the approximate location of each well. The constant head at each well was specified at an elevation several feet lower than the nearby constant head boundary specified at the down-gradient end of the model grid. This configuration of the model provided a sink for groundwater flowing toward the Allen Well Field pumping wells.

Model Results

The flow model was run as a steady-state solution while the MT3D transport model simulations were run with a duration of fifty years to assess the long-term plume behavior in the Memphis aquifer once the PCE and TCE plumes had reached the aquitard window. The steady-state groundwater contours predicted by the MODFLOW simulations are shown on Figure 16. From this figure it is apparent that the representation of the Allen Well Field production wells used in the model significantly influence the rate and direction of groundwater flow in the vicinity of these wells.

Six different scenarios were run with the Memphis Aquifer model. The first four consisted of runs simulating the transport of PCE and TCE assuming both finite and infinite sources. All of these runs assumed that attenuation was occurring during transport through the Memphis Aquifer. Two more simulations were also run for the PCE plume to evaluate the extent of contamination in the Memphis aquifer if no attenuation was assumed. For these runs the worst case PCE simulation (with an assumed infinite source and no fluvial aquifer attenuation) and the best case PCE simulation (with an assumed finite source and fluvial aquifer attenuation) were run assuming no attenuation in the Memphis Aquifer. The six different source area persistence and degradation scenarios were run over a fifty-year period using MT3D. For clarity in the report, the most probable scenarios are presented here. Namely, it is most likely that a finite source is located in the fluvial aquifer (it is suspected that about 200 pounds of contaminant mass is present in the soil and groundwater at the site) and that attenuation occurs, since the calibration curve shows that to fit the field data, the model had to assume attenuation. See Figures 17 and 18 for results for the PCE and TCE plumes, respectively. On the other hand, it is unknown to what extent attenuation occurs in the Memphis Aquifer. Therefore two additional simulations were performed for PCE to show the best case and worst case scenario results assuming that no attenuation occurs in the Memphis aquifer. The results of these analyses are summarized in Figures 19 and 20.

Since the BIOSCREEN simulations suggest that the simulated TCE concentrations reaching the window are about one-half that estimated for PCE, simulations assuming no attenuation in the Memphis Aquifer are shown only for PCE. Simulation of TCE transport under these same conditions would result in significantly lower simulated TCE concentrations within the Memphis Sand Aquifer than is predicted for PCE.

The results of the two simulations assuming attenuation in the Memphis Aquifer suggest that the influence of attenuation acts to limit the downgradient migration of the VOC plumes. While the specific shape and concentration distribution within each plume varies from simulation to simulation, the overall downgradient extent of migration is quite limited, primarily due to the effects of attenuation during transport. In each of these scenarios the extent of the contaminant plumes remain within the borders of the MI throughout the 50 year simulation.

In the two simulations assuming no attenuation in the Memphis Aquifer, the simulated PCE plume moves significantly further downgradient than in the previous runs, but still does not quite reach the Allen Well Field wells after 50 years of simulation time. The migration distance under this alternative however, clearly predicts movement of the contaminant plume beyond the boundary of the MI.

Conclusions

The purpose of this study was to determine the behavior of shallow PCE and TCE plumes in the fluvial and intermediate aquifers at the Main Installation site of the Memphis Depot. The plumes of interest are located close to a breach in the confining layer between the intermediate aquifer and the Memphis Sand Aquifer (referred to herein as the aquitard window). Through the aquitard window contaminants can enter the Memphis Aquifer and potentially travel down-gradient towards the production wells of the Allen well field, which supply a portion of the drinking water supply to the Memphis area. The first part of the modeling analysis focused on contaminant transport through the shallow fluvial and intermediate aquifers while the second part of the analysis involved simulating the fate and transport of the VOC plumes once they had entered the Memphis aquifer. It should be noted that during this analysis it was assumed that all of the PCE source mass near MW-39A flows north toward the aquitard window. In reality, groundwater elevations measured in the fluvial aquifer suggest some portion of the groundwater in this area may flow to the south. If this is the case, the water quality impacts predicted herein may be greater than what will actually occur.

The simulations resulted in predicted VOC plumes that move through the Memphis Aquifer towards the Allen well field, but do not reach it within a fifty-year timeframe. The concentrations that enter the Memphis Aquifer are well above the MCL for both PCE and TCE. If degradation at the rate observed in the fluvial aquifer is assumed to also be occurring in the Memphis Aquifer, then the plumes are projected to completely degrade before reaching the Allen Well Field, and in fact never leave the property boundary of the Main Installation. However, if no degradation is assumed to occur within the Memphis

Aquifer, the worst case PCE plume was predicted to travel significantly further down-gradient, move beyond the Main Installation property boundaries, but still not quite reach the nearest wells of the Allen Well Field after 50 years of travel.

It is recommended that monitoring of contaminant concentrations in wells closest to, and within, the aquitard window be continued to detect any significant increase in mass flux to the window. In addition, monitoring wells drilled into the Memphis Sand Aquifer should be considered to collect aquifer specific water quality information between the aquitard window and the Allen Well Field.

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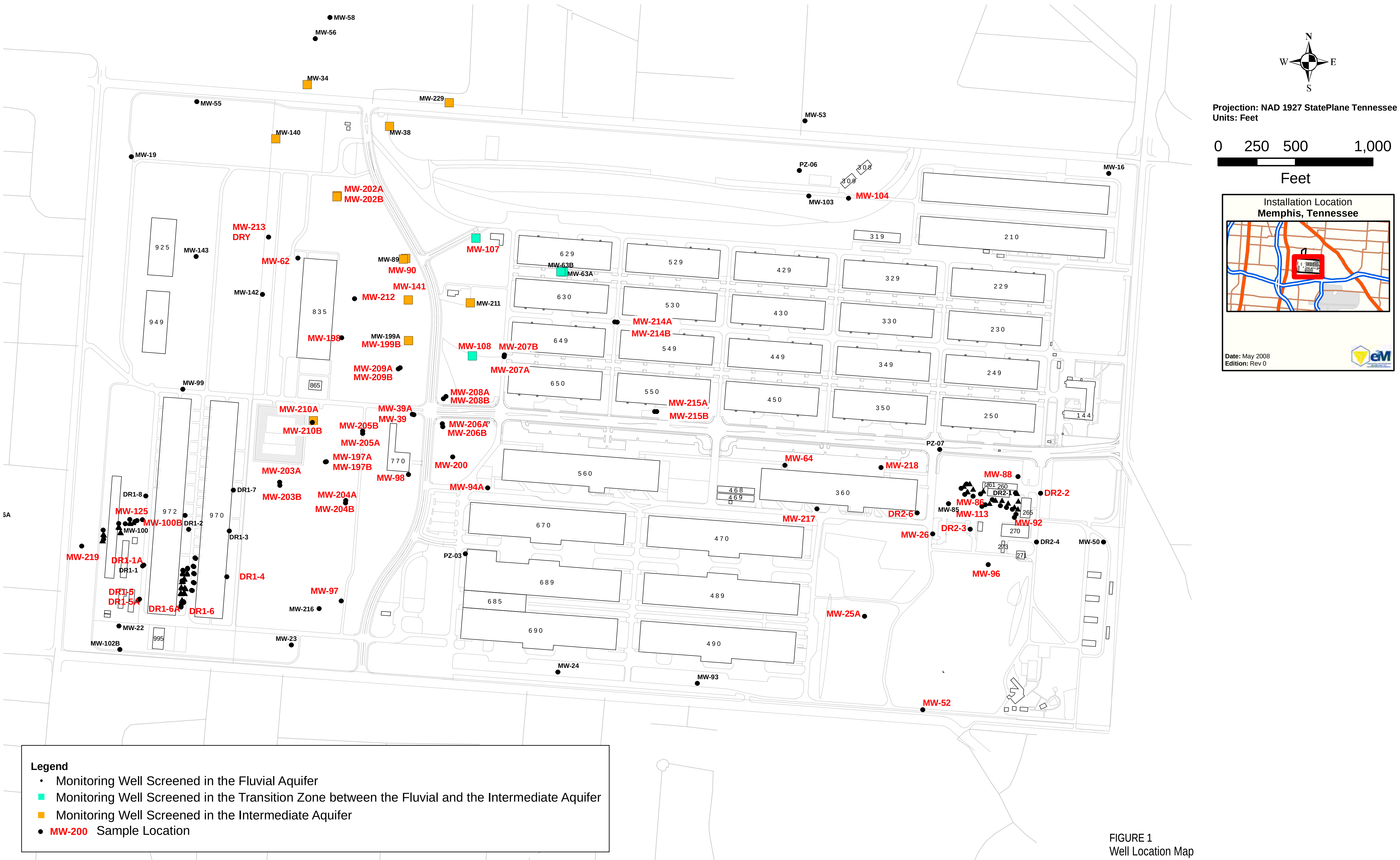

Legend
- Monitoring Well Screened in the Fluvial Aquifer
- Monitoring Well Screened in the Transition Zone between the Fluvial and the Intermediate Aquifer
- Monitoring Well Screened in the Intermediate Aquifer
- MW-200 Sample Location

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FIGURE 1
Well Location Map
April 2008 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., April 2008 Long-Term Monitoring Report, May 2008, Rev.0

ES022009001ATL Fig1.ai

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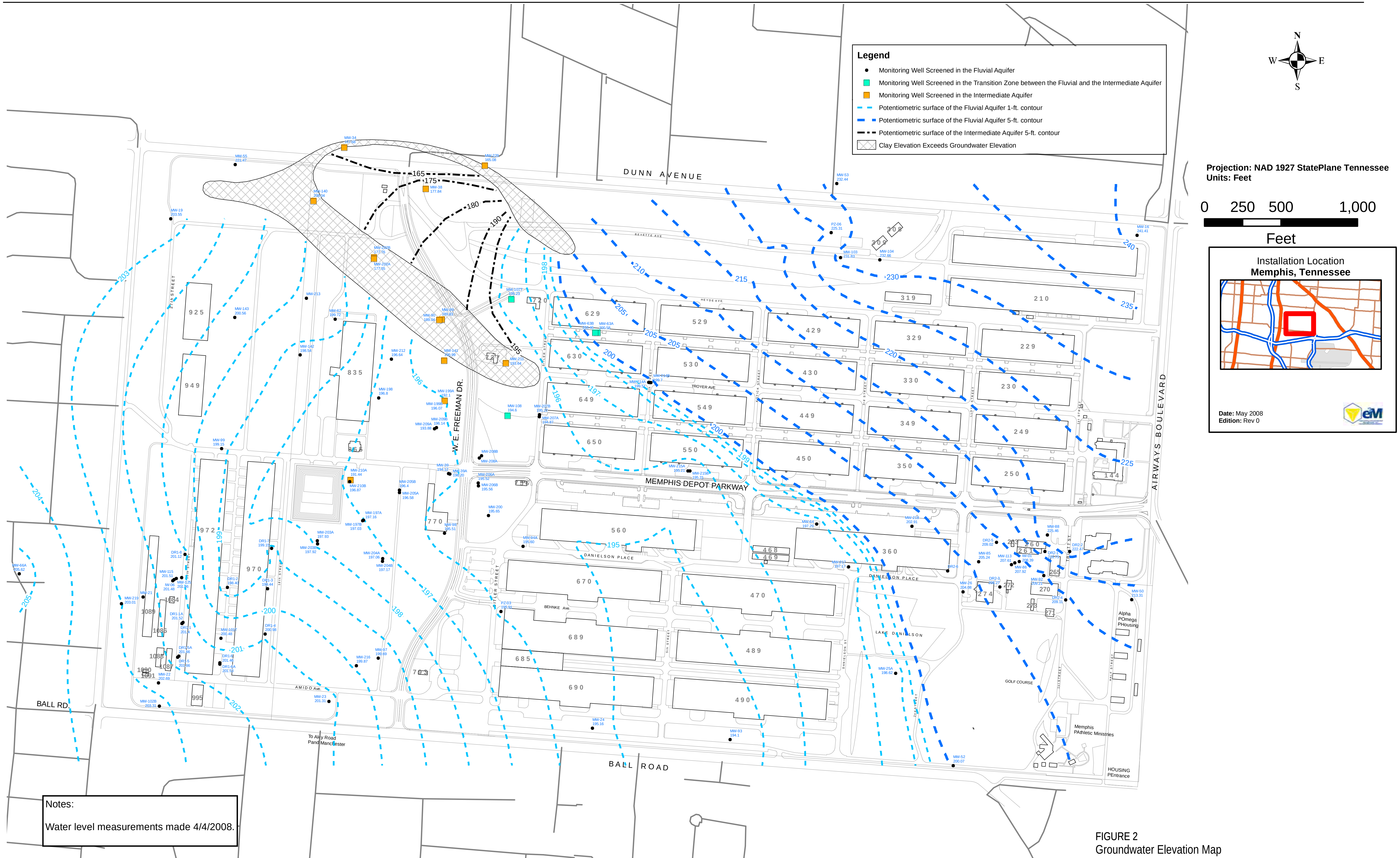

FIGURE 2
Groundwater Elevation Map
April 2008 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., April 2008 Long-Term Monitoring Report, May 2008, Rev.0

ES022009001ATL Fig2.ai

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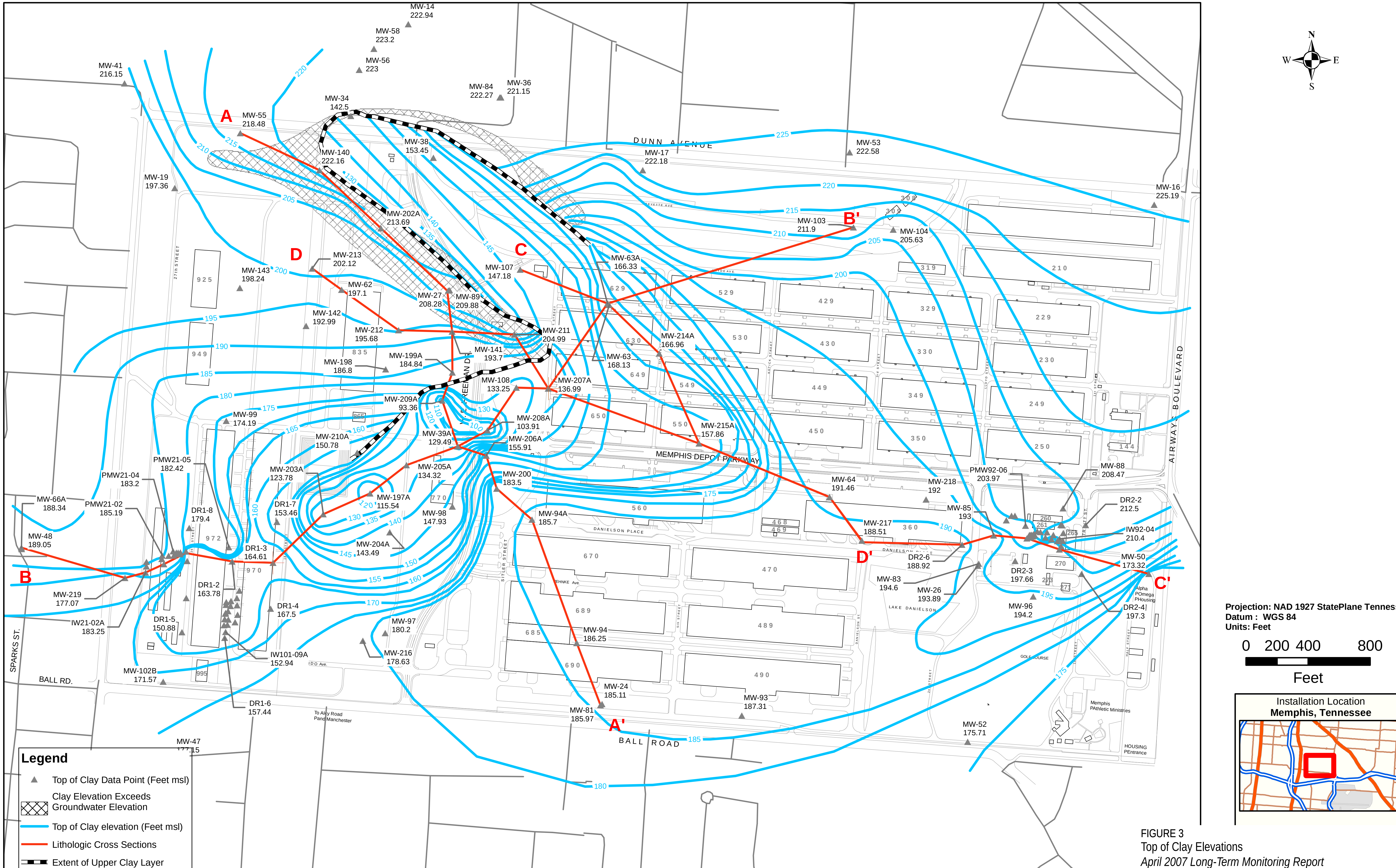

FIGURE 3
Top of Clay Elevations
April 2007 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., Phase 2 Wells and April 2007 LTM Report, July 2007, Rev.0

ES022009001ATL Fig3.ai

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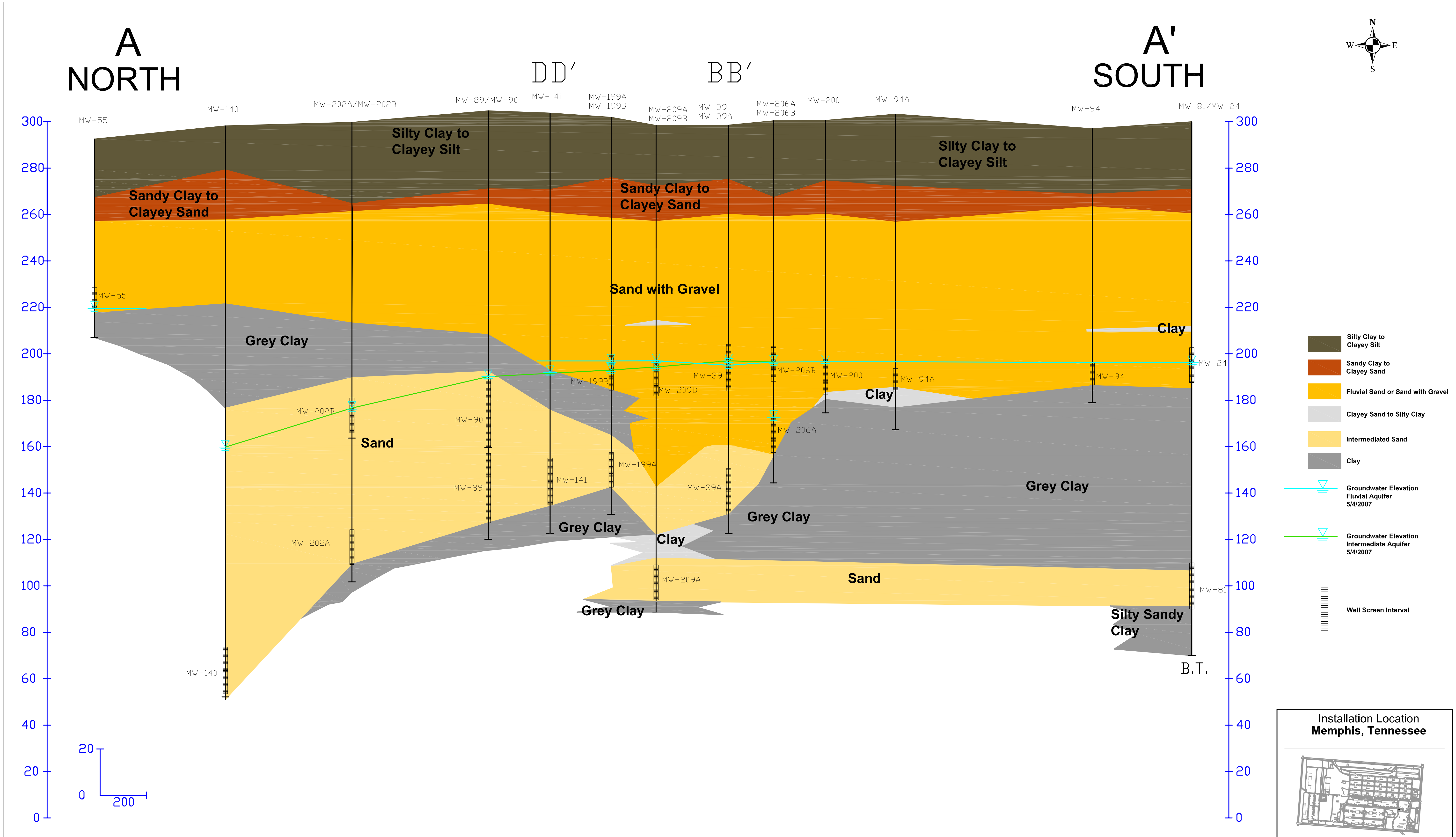

FIGURE 4
Lithologic Cross-Section A-A'
April 2007 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., Phase 2 Wells and April 2007 LTM Report, July 2007, Rev.0

FIGURE 5
Intermediate Aquifer Groundwater Contours
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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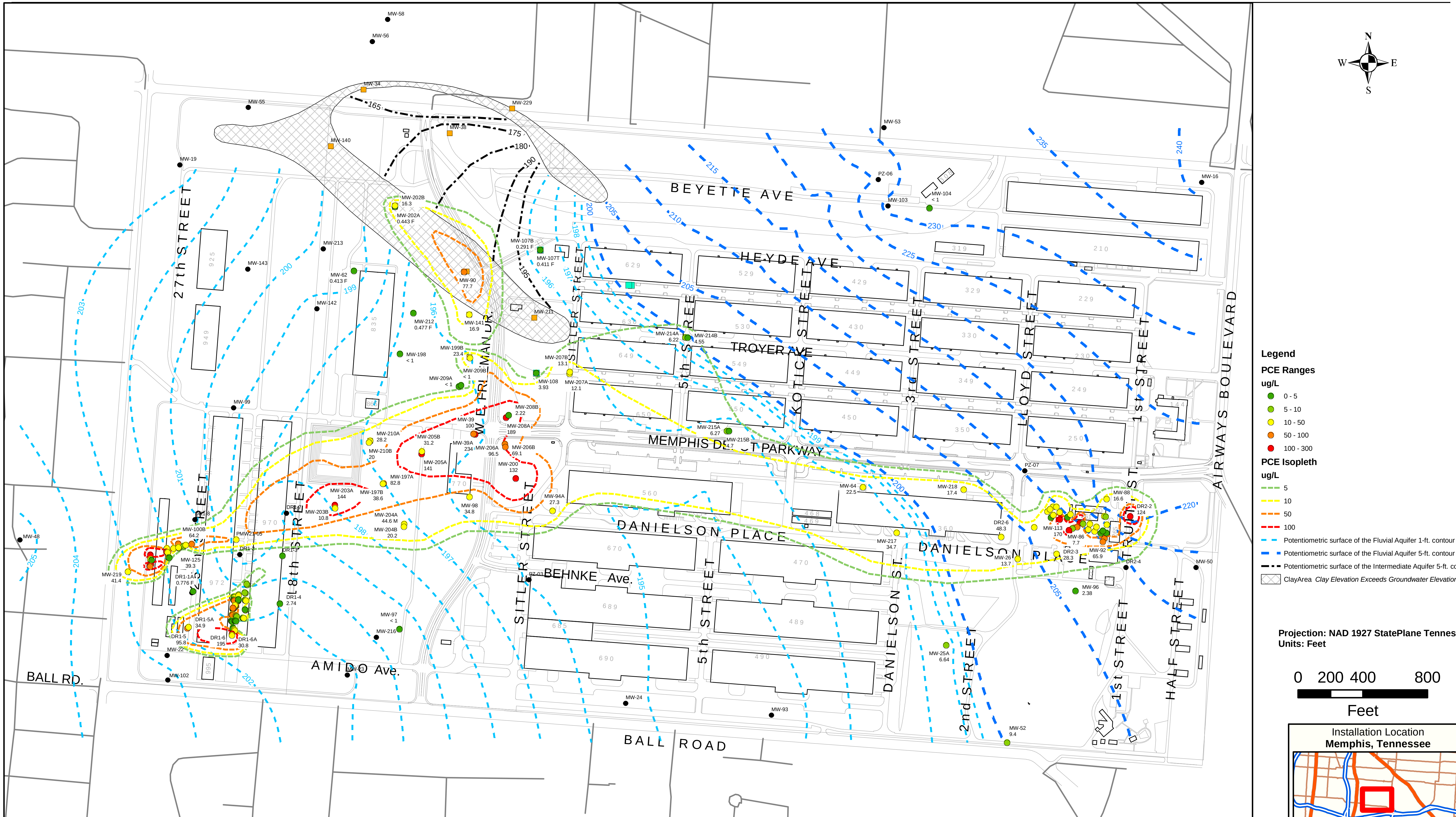

Notes:

1. Isopleths results combine results from both the Long Term Monitoring sample event (4/7/08 - 4/9/08) and the EBT- sample event (3/10/08 - 3/19/08).

2. Only LTM results shown for clarity.

FIGURE 6
PCE Isopleth Map
April 2008 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., April 2008 Long-Term Monitoring Report, June 2008, Rev.0

ES022009001ATL Fig6.ai

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Notes:

1. Isopleths results combine results from both the Long Term Monitoring sample event (10/1/07 - 10/18/07) and the EBT- sample event (9/10/07 - 9/20/07).

G:\32020160\MI Source Area Investigation\GIS\MIP Status Report

FIGURE 7
MI Groundwater Plumes - PCE/TCE October 2007
April 2007 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., Main Installation Source Area Investigation, October 2008, Rev.0

ES022009001ATL Fig7.ai

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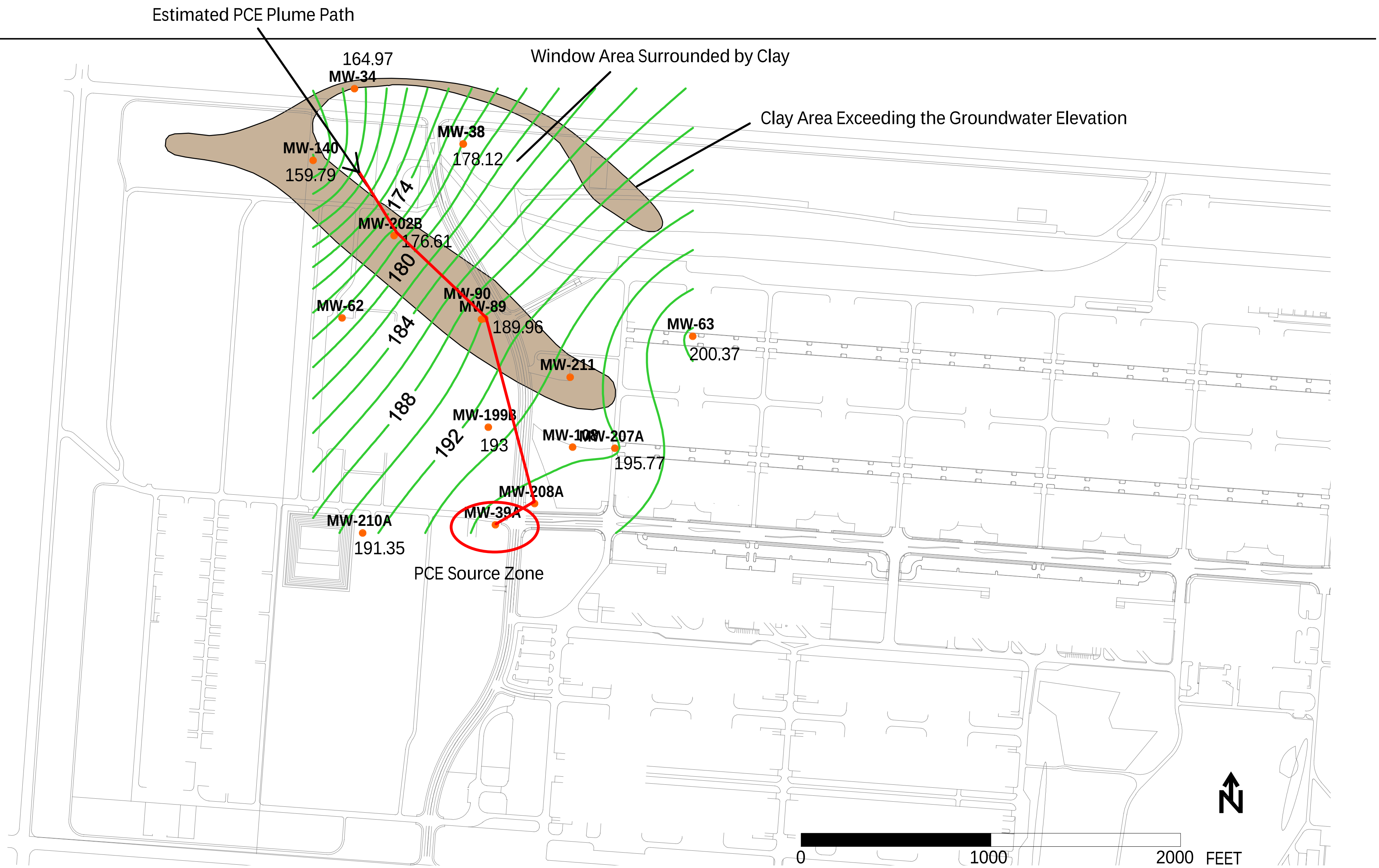
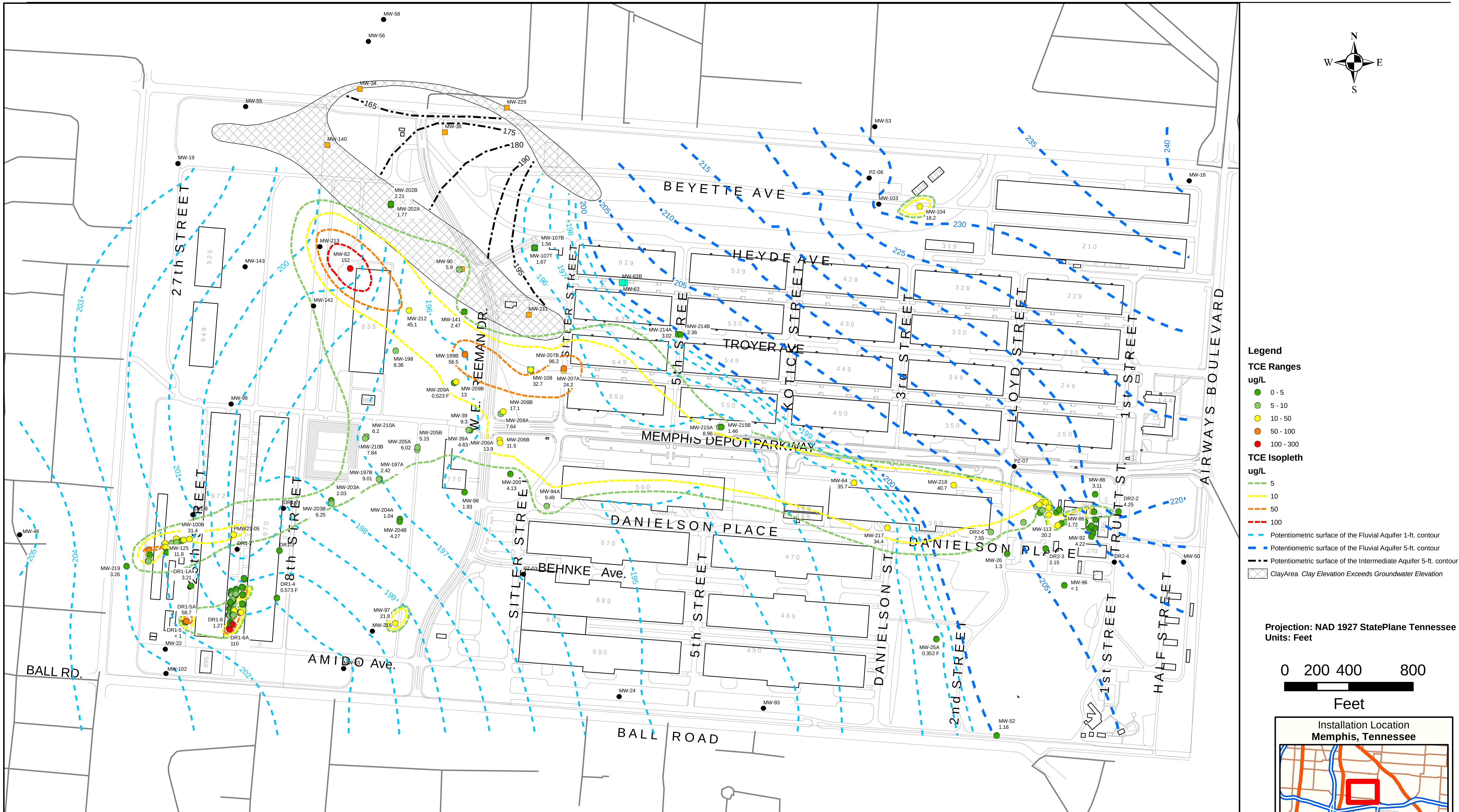


FIGURE 8
Intermediate Aquifer Groundwater Contours and Assumed PCE Plume Path
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee



Notes:

1. Isopleths results combine results from both the Long Term Monitoring sample event (4/7/08 - 4/9/08) and the EBT- sample event (3/10/08 - 3/19/08).

2. Only LTM results shown for clarity.

FIGURE 9
TCE Isopleth Map
April 2008 Long-Term Monitoring Report
Main Installation Defense Depot, Memphis, Tennessee

Source: Engineering-Environmental Management, Inc., April 2008 Long-Term Monitoring Report, June 2008, Rev.0

ES022009001ATL Fig9.ai

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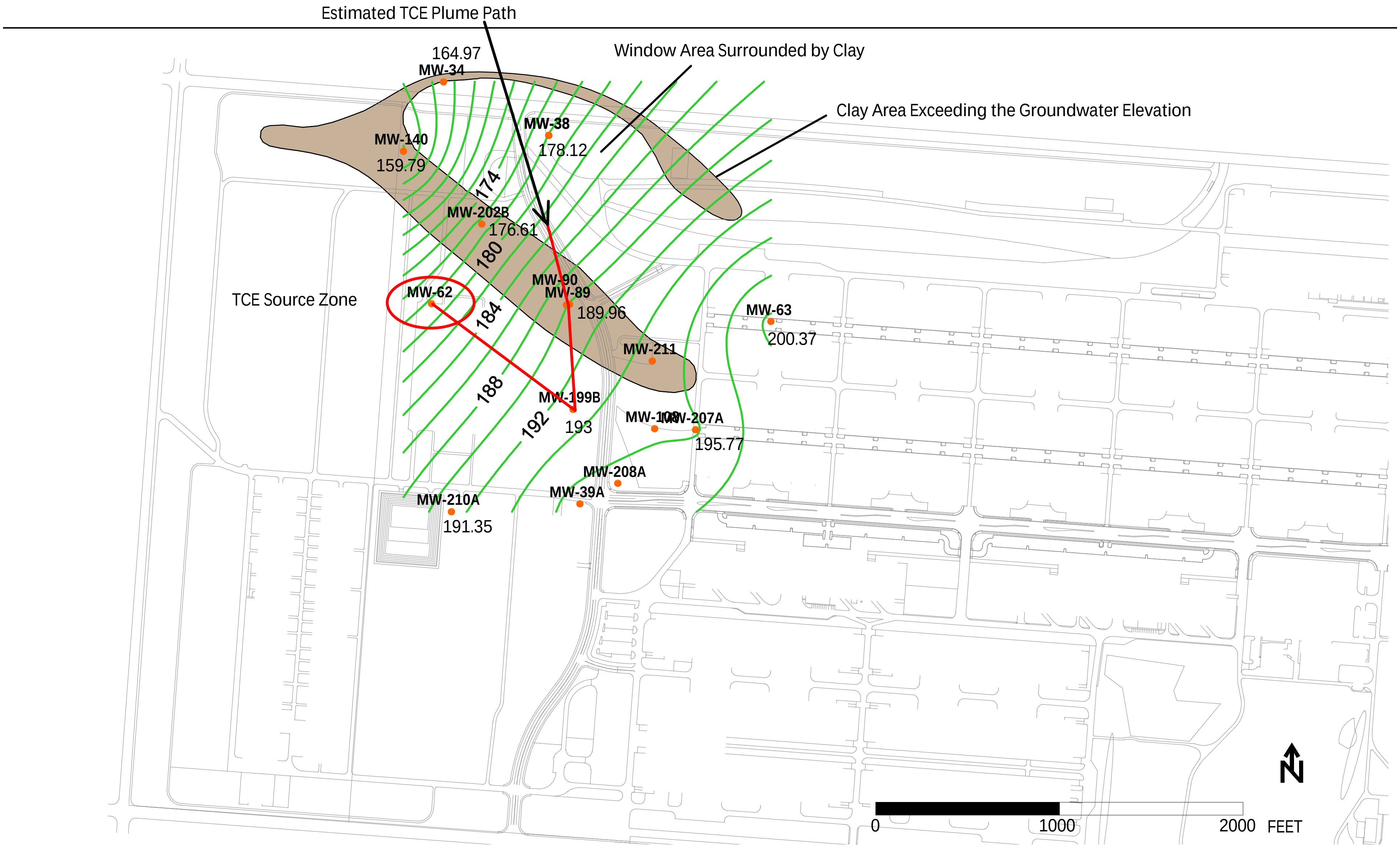
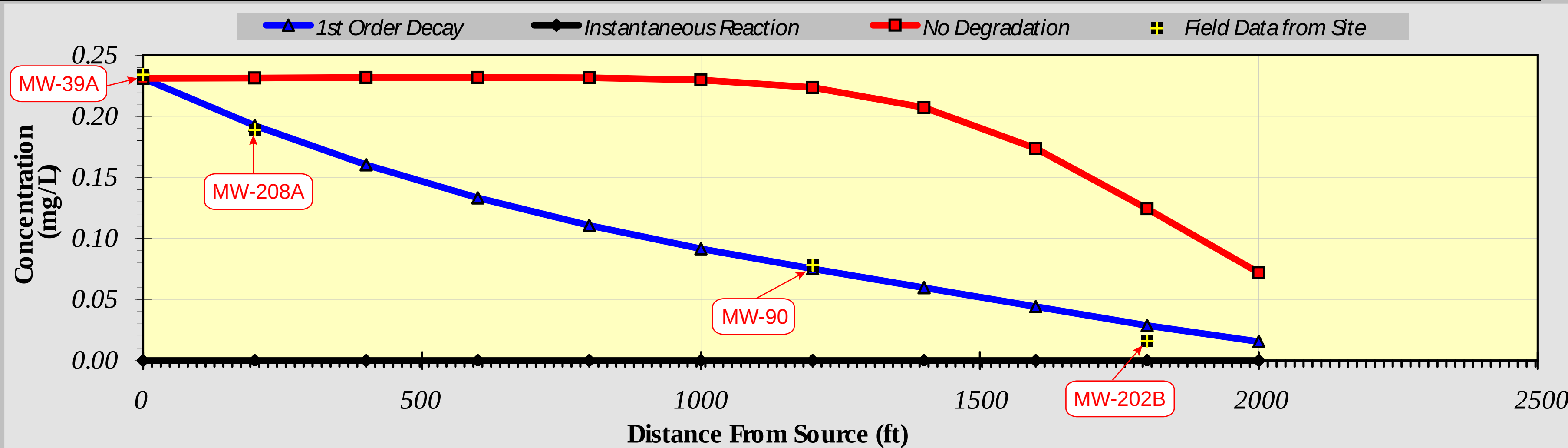


FIGURE 10
Intermediate Aquifer Groundwater Contours and Assumed TCE Plume Path
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	0.231	0.231	0.232	0.232	0.232	0.230	0.224	0.207	0.174	0.124	0.072
1st Order Decay	0.231	0.192	0.160	0.133	0.111	0.092	0.075	0.060	0.044	0.029	0.016
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.234	0.189					0.078			0.016	



Replay Animation

Next Timestep

Prev Timestep

Time:

3.5 Years

Return to Input

Recalculate This Sheet

FIGURE 11
Attenuation Rate Calibration with Field Data for PCE
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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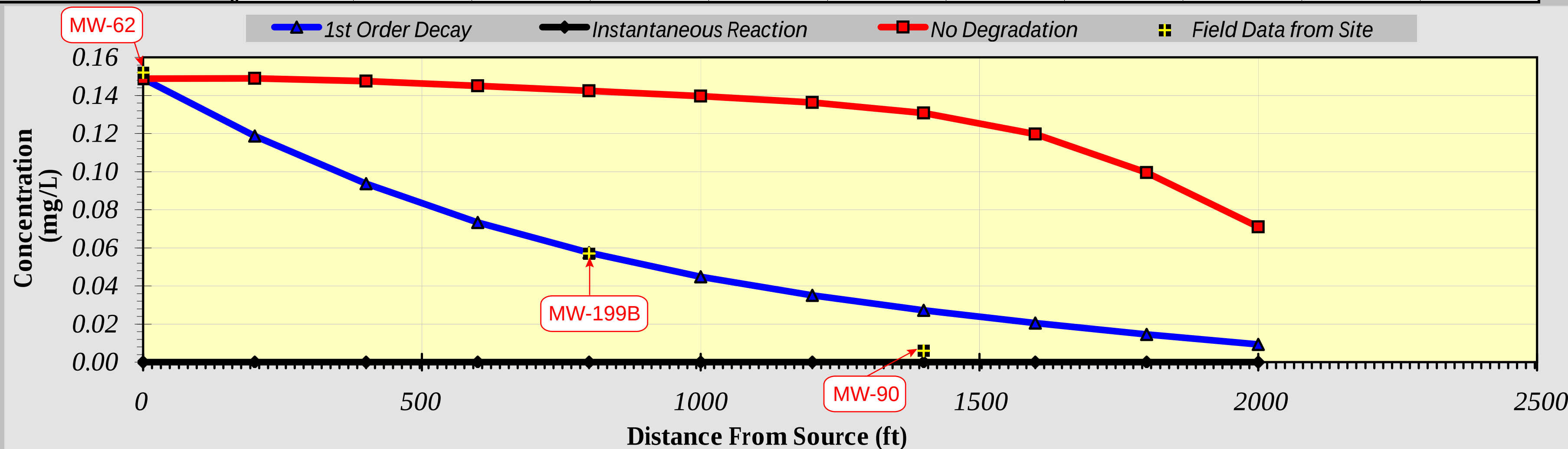
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	0.149	0.149	0.148	0.145	0.142	0.140	0.136	0.131	0.120	0.099	0.071
1st Order Decay	0.149	0.119	0.094	0.073	0.057	0.045	0.035	0.027	0.021	0.015	0.009
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.152				0.057			0.006			



Replay Animation

Next Timestep

Prev Timestep

Time:

3.0 Years

Return to Input

Recalculate This Sheet

FIGURE 12
Attenuation Rate Calibration with Field Data for TCE
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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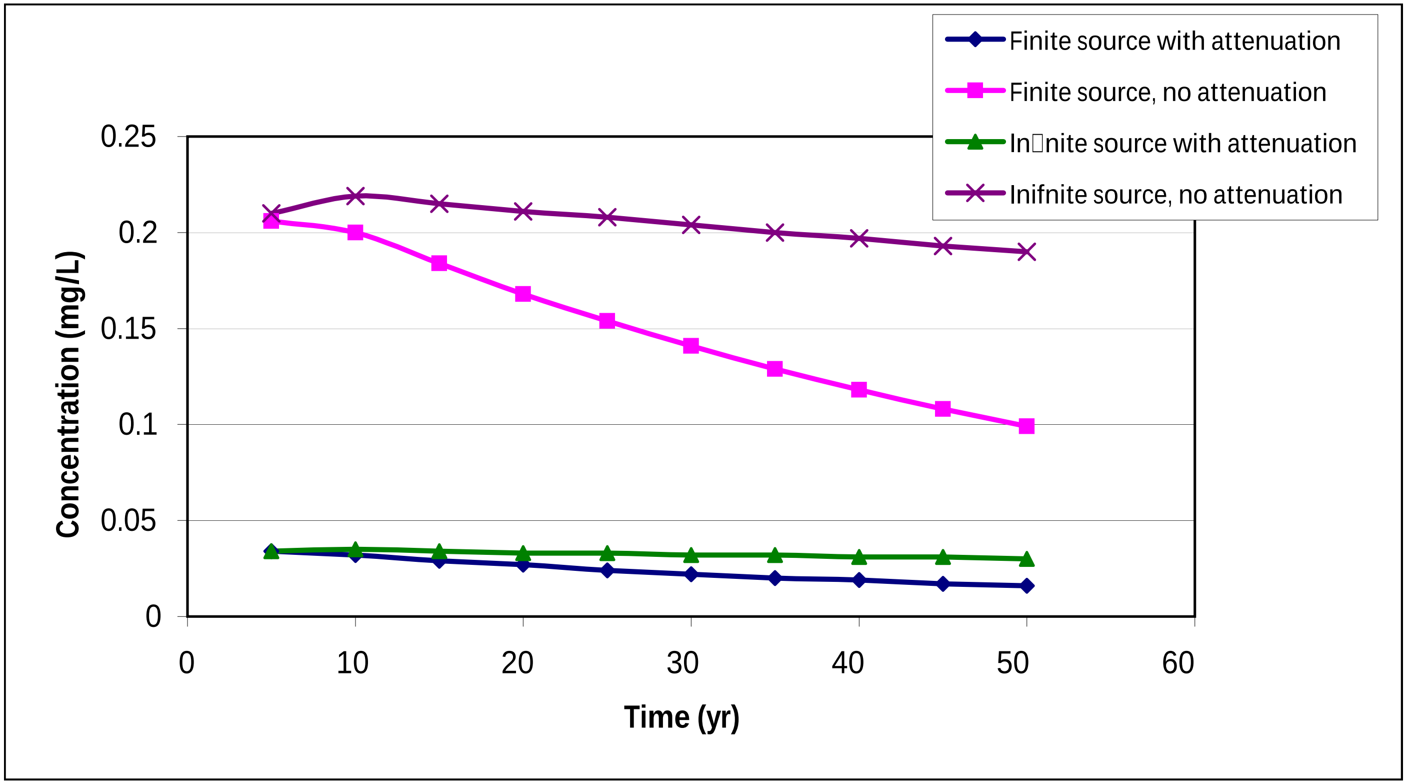

FIGURE 13
Bioscreen Simulated Concentration Time Series at the Aquitard Window for PCE
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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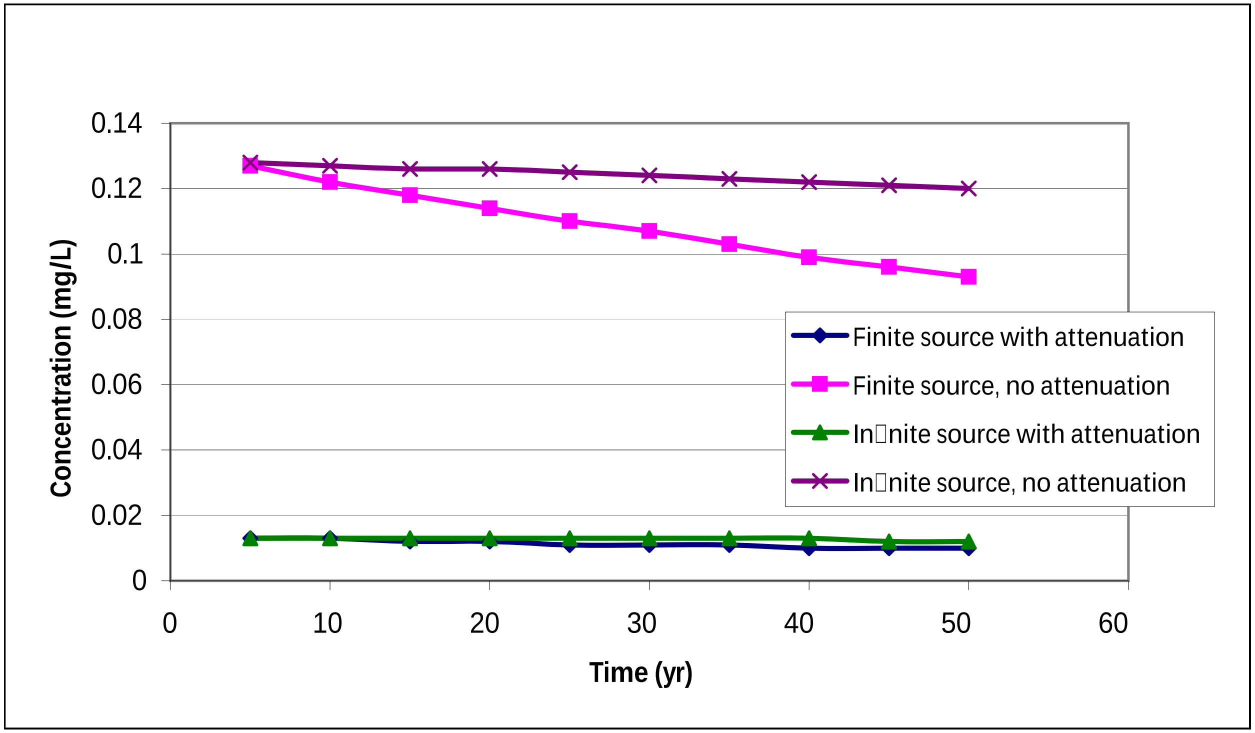

FIGURE 14
Bioscreen Simulated Concentration Time Series at the Aquitard Window for TCE
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

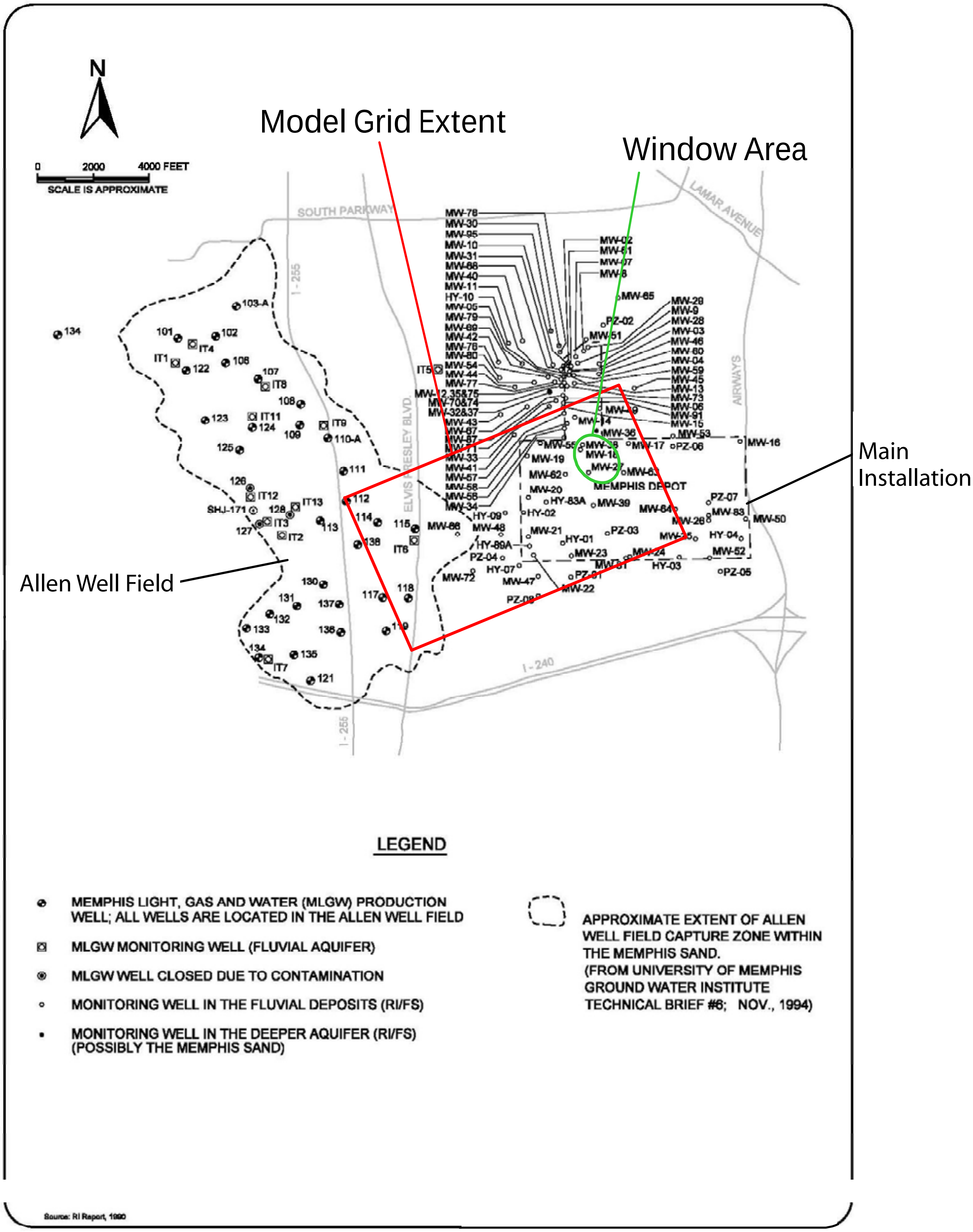

FIGURE 15
Allen Well Field Location Relative to the Memphis Depot
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

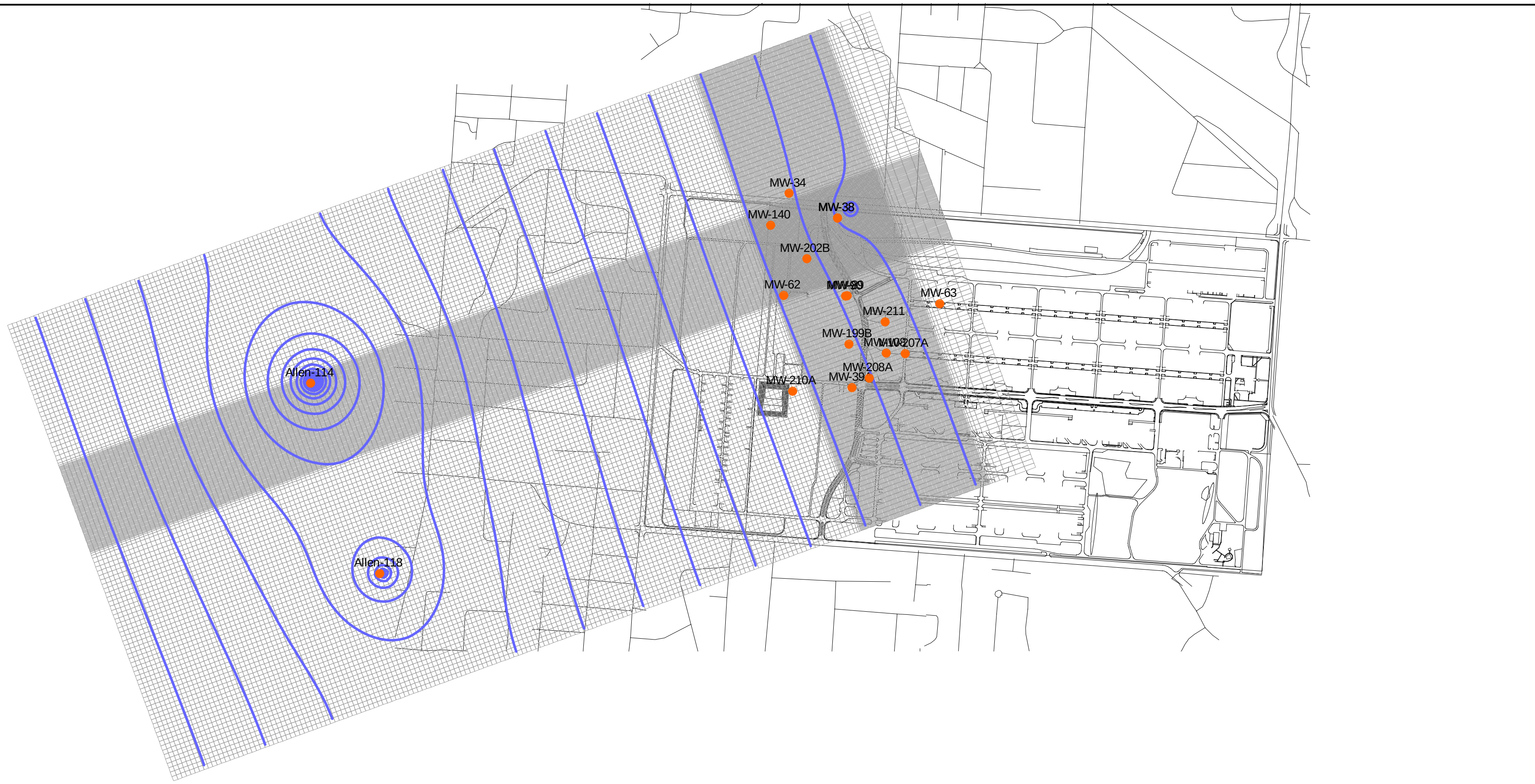

FIGURE 16
Memphis Aquifer Model Grid and Simulated Layer 1 Groundwater Elevations
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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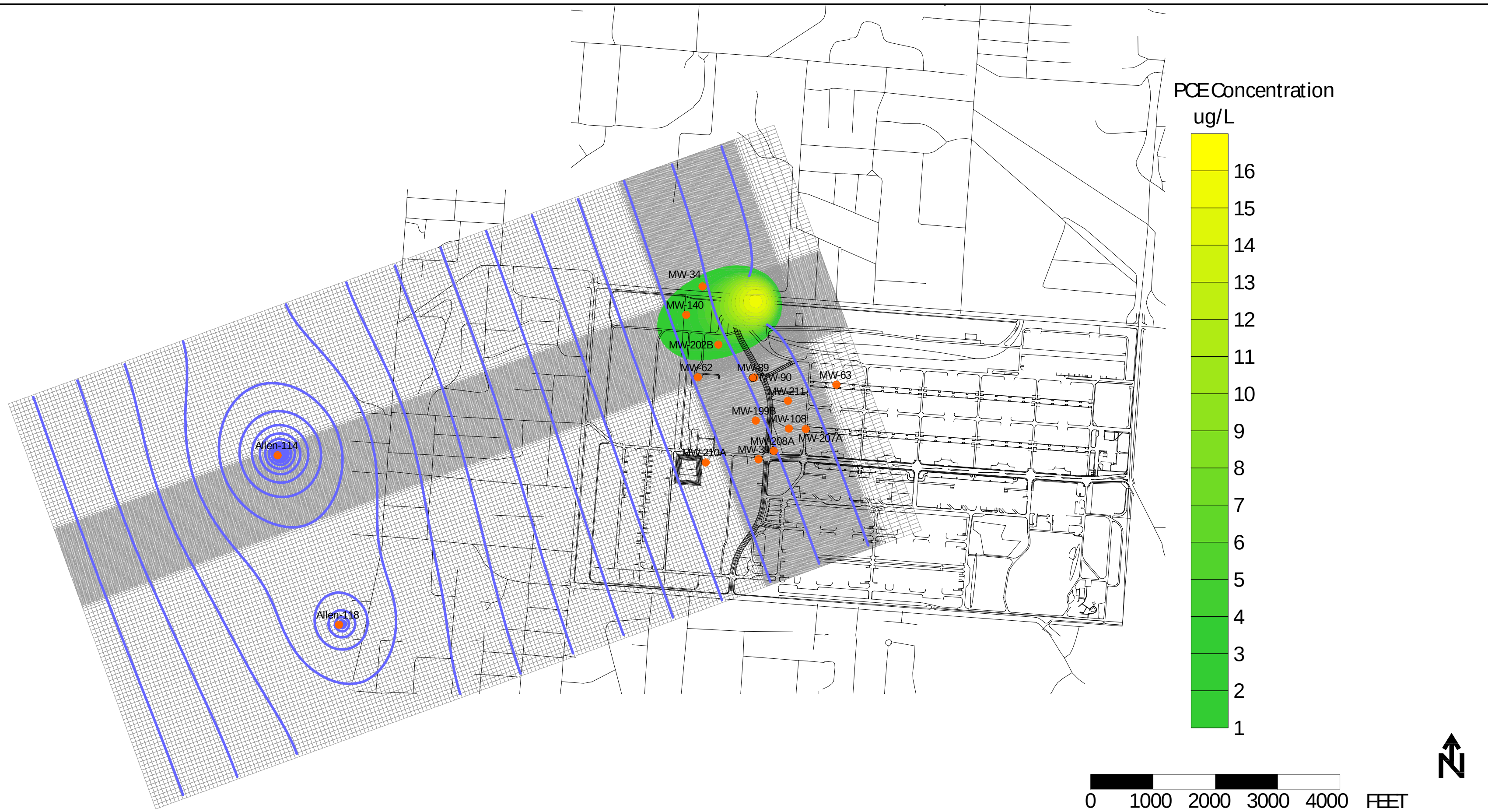

FIGURE 17
Simulated PCE Concentrations in the Memphis Aquifer - Layer 1 after 50 Years, Finite Source with Attenuation in the Fluvial Aquifer and Attenuation in hte Memphis Aquifer
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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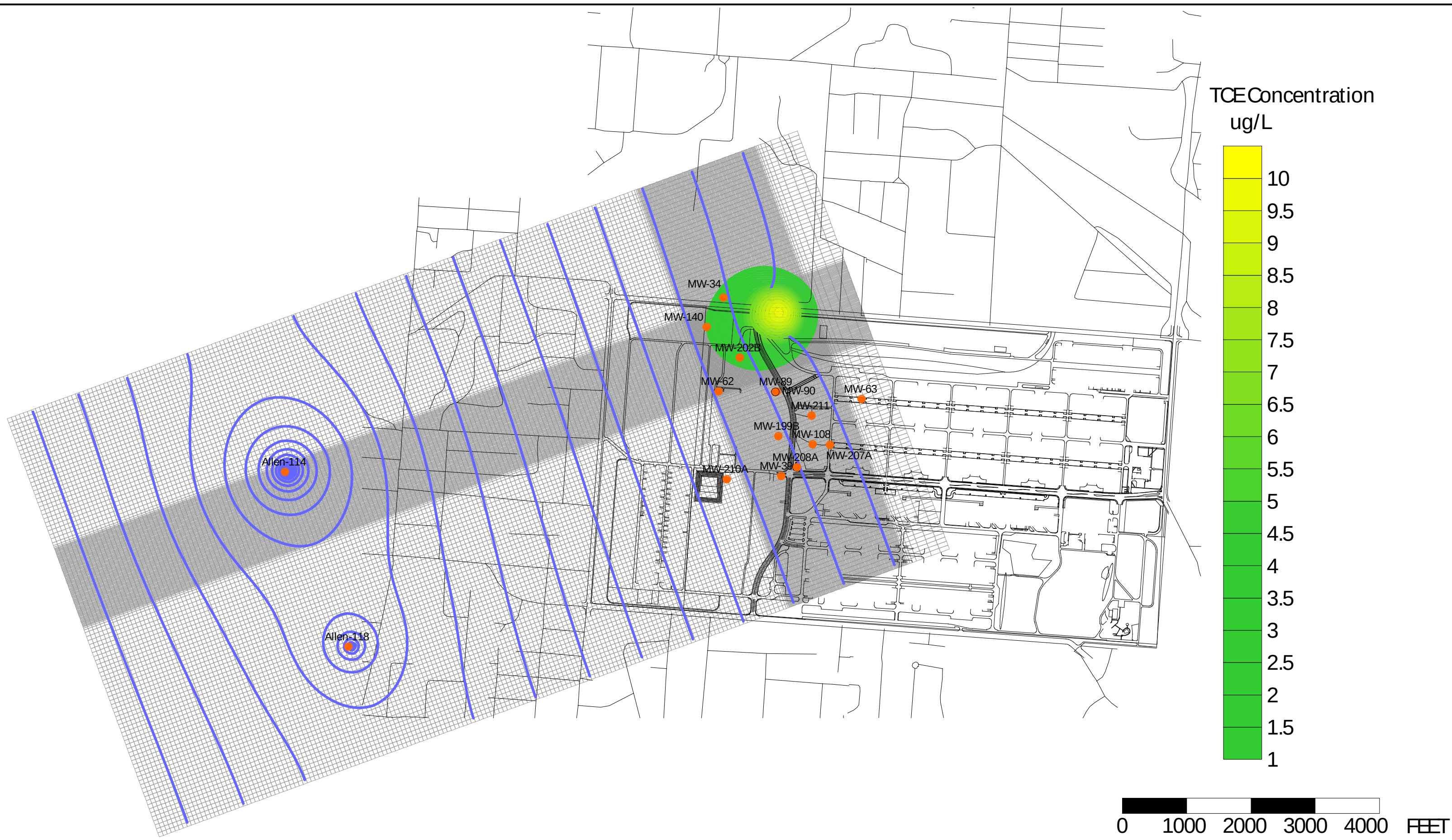

FIGURE 18
Simulated TCE Concentrations in the Memphis Aquifer - Layer 1 after 50 Years, Finite Source with Attenuation in the Fluvial Aquifer and with Attenuation in the Memphis Aquifer
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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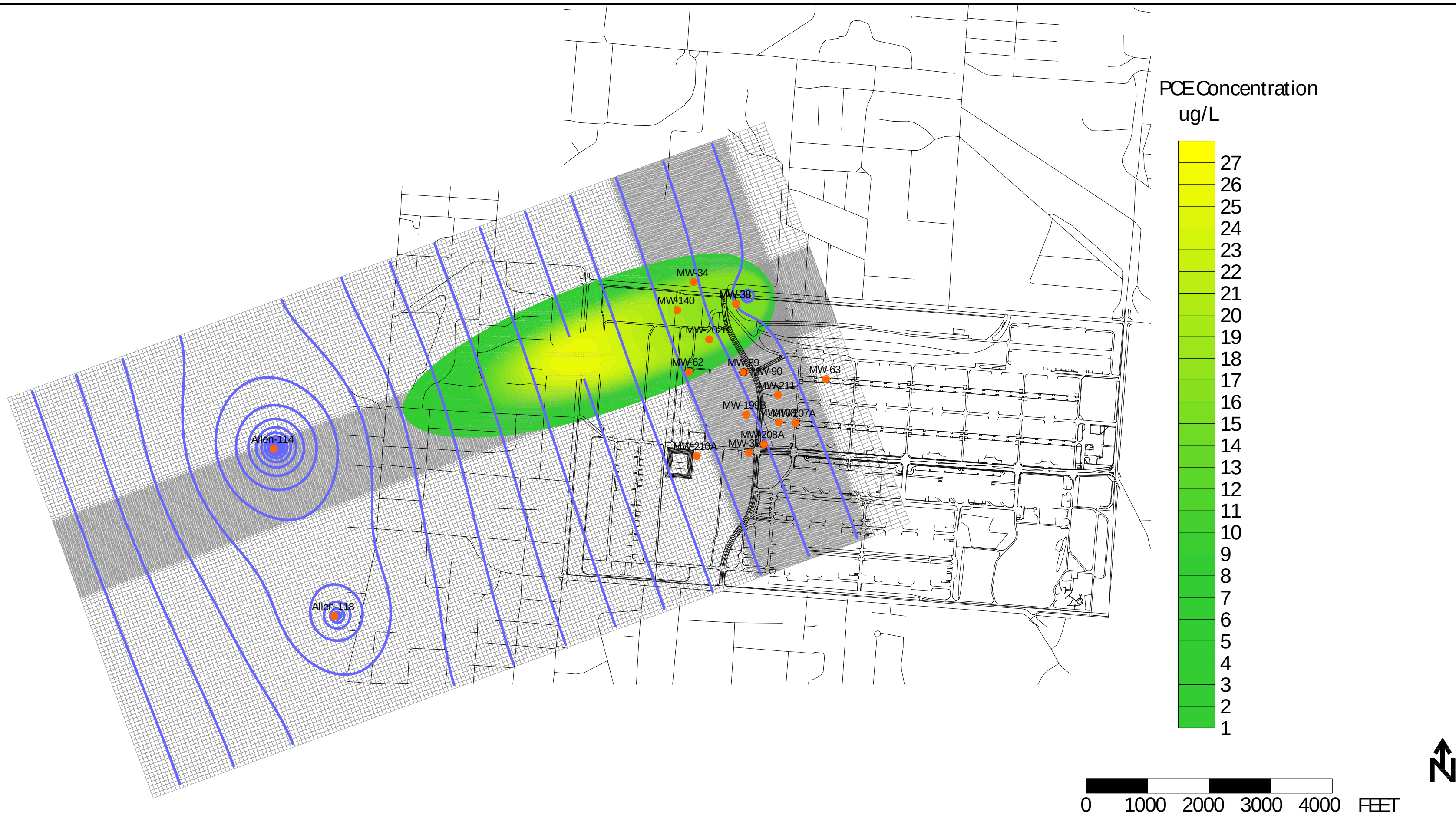

FIGURE 19
Simulated PCE Concentrations in the Memphis Aquifer - Layer 1 after 50 Years, Finite Source with Attenuation in the Fluvial Aquifer and no Attenuation in the Memphis Aquifer
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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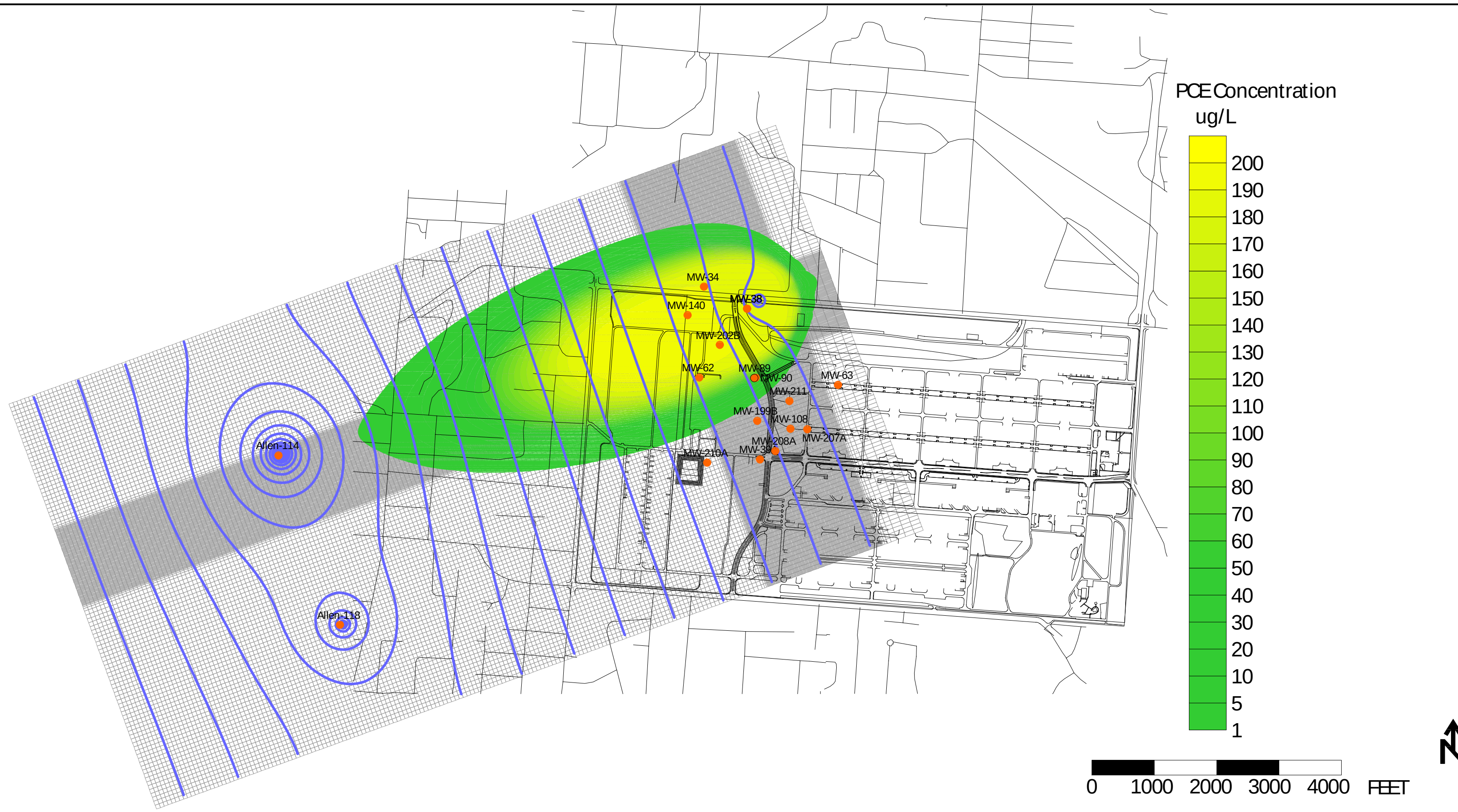

FIGURE 20
Simulated PCE Concentrations in the Memphis Aquifer - Layer 1 after 50 Years, Infinite Source with no Attenuation in the Fluvial Aquifer and no Attenuation in the Memphis Aquifer
Contaminant Plume Modeling Report, January 2009
Main Installation Defense Depot, Memphis, Tennessee

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